

The Solar Corona, as shown in Photographs taken during Total Eclipses. By W. H. Wesley.

(Communicated by the Secretaries.)

Having had occasion to make a very minute examination of the negatives taken during several of the recent solar eclipses, I have thought that it might be of interest to give an account of some of the prominent features of the photographic corona in the different years. I do not attempt to propound any theories, and shall only mention some of the current hypotheses with a view of showing how far they appear to be supported or contradicted by the photographic records.

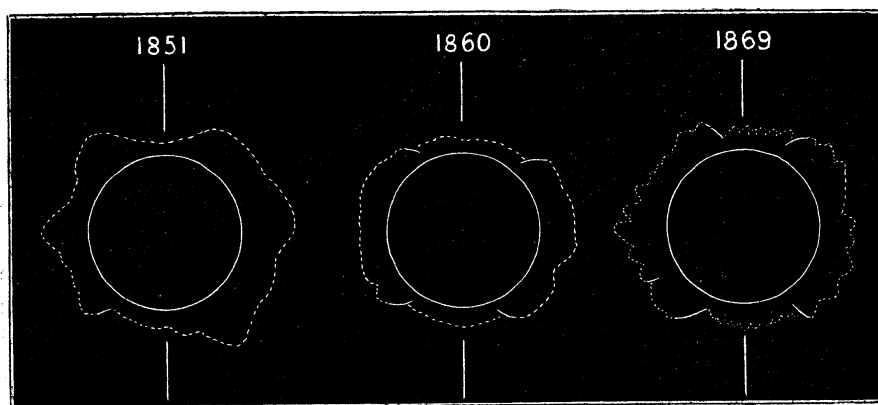
Mr. Ranyard in the eclipse volume of the *Memoirs* has so fully discussed the photographs taken previously to 1878, that in most cases it will only be necessary very briefly to allude to them.

One of the most striking features in the corona of almost all the years under examination is the existence of a more or less well-marked polar rift, roughly, but perhaps never exactly, corresponding with the Sun's axis of rotation, to which it appears sometimes inclined as much as 30° . In most cases this rift is shown at both poles, but sometimes at one only; in 1882 it does not appear at all. The northern and southern rifts are seldom strictly opposite to one another, so that a line drawn through them does not pass through the centre of the Sun. The polar rifts are generally filled with shorter, straighter, and more radial rays, with a background of less density than in other parts of the corona.

On either side of the polar rift there usually appears a somewhat conical mass, composed of rays curving towards each other, forming groups of what Mr. Ranyard has appropriately called "synclinal structure," which give the quadrilateral or cruciform appearance frequently shown in corona drawings. They mostly seem to be situated over the zones of maximum sunspot activity, and have frequently greater extension than other parts of the corona.

Eclipse of 1851, July 28.

Dr. Busch's daguerreotype is remarkable as the first instance of a successful photograph of the corona. It shows the general form to a height nowhere much exceeding $\frac{1}{4}$ of a solar diameter. The corona is symmetrical and of hexagonal form, with a well-marked rift not far from the north and south poles, the southern rift being much the broader. On either side of these rifts are indications of synclinal masses; there are also similar masses in the equatorial regions fairly corresponding on each side. The orientation of the plate is rather uncertain. Wolf gives 64.2 as the relative number of sunspots for July 1851.

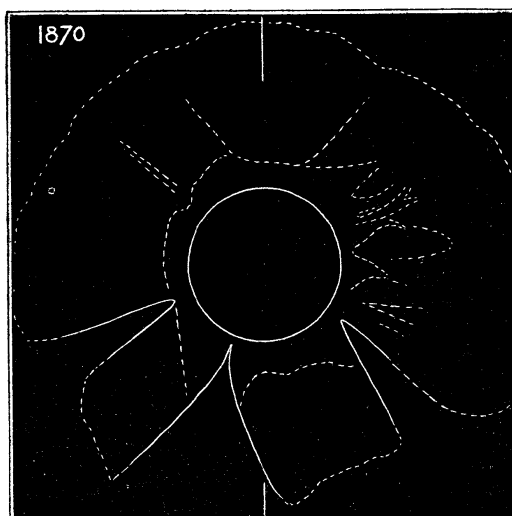


Eclipse of 1860, July 18.

In the photographs taken at Desierto de las Palmas, of which I have only seen positive copies, there is shown a very broad rift towards the south pole, and a less marked one on the north. The character of the synclinal groups is not clearly marked. The corona is fairly symmetrical about a line not much inclined from the Sun's axis. Wolf's relative number of sunspots is 94.9.

Eclipse of 1869, August 7.

I have not seen the original negatives of the photographs taken at Shelbyville, which are the only ones which show any considerable extent of corona. The northern and southern polar rifts are clearly marked and very broad. The bases of the four synclinal groups can also be clearly made out, especially that in the north-west quadrant. The general axis of symmetry is slightly inclined to the north-west and south-east of the Sun's axis. Wolf's relative number of sunspots is 77.6.



Eclipse of 1870, Dec. 22.

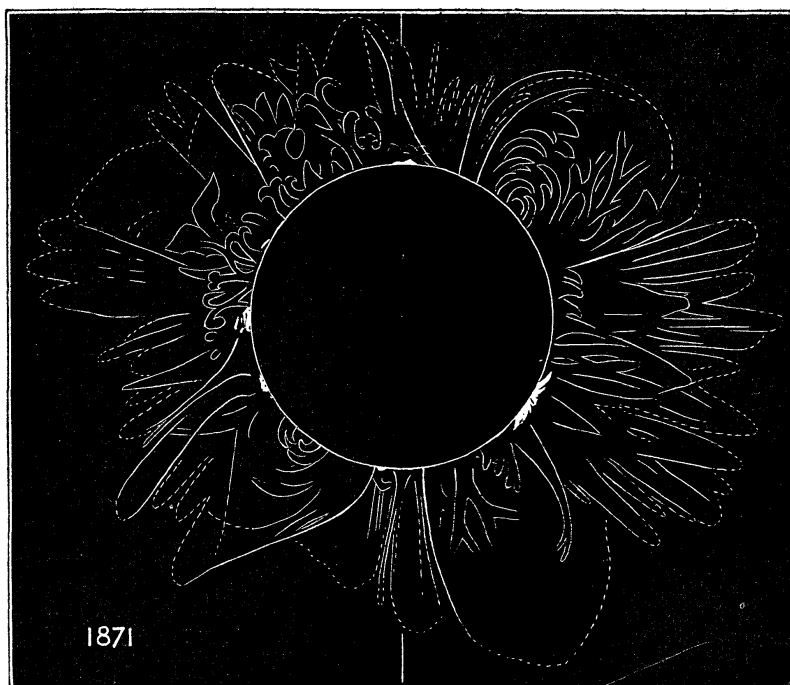
Mr. Brothers's negative, taken at Syracuse, shows a great extent of corona, reaching in some parts quite 40' from the limb.

June 1887.

as shown in Photographs.

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The general outline is somewhat circular, with a quadrilateral area of greater brightness, brighter on the western side. The northern polar rift is broad and ill-defined; to the east of the south pole is a much narrower and more sharply defined rift, easily traceable to the limb. To the east and west of this are other rifts, and there is structure evidently synclinal to the north-west; otherwise the photograph shows but little detail. The general axis of symmetry appears inclined to the north-west and south-east of the Sun's axis as much as 20° , but the orientation is not very certain. The eclipse occurred at a period of great solar activity, Wolf's relative monthly number being 135.4



Eclipse of 1871, Dec. 12.

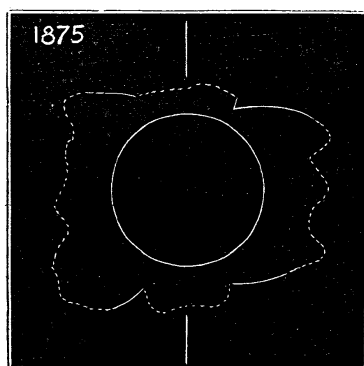
Lord Lindsay's and Col. Tennant's excellent series of negatives show a corona remarkably symmetrical, about a line inclined about 10° to the north-west and south-east of the Sun's axis. The northern and southern polar rifts are well defined, nearly opposite to one another, and very similar in character. The four synclinal groups are well marked, appearing to indicate zones of synclinal structure extending nearly from the pole to about 40° north and south latitude. These groups are generally separated from the equatorial portions by narrow definite rifts. The western margin of the south-east synclinal group shows a distinct tendency to double curvature—a form which reappears in 1883 and 1885. The extension is greatest in the equatorial regions, giving a somewhat hexagonal form to the corona. The great polar rifts are filled with short straight rays.

The greatest extent of the photographic corona does not exceed $27'$, but the minuteness of the detail near the limb, which

with a strong transmitted light can be seen through the densest part of film, has never been equalled in any subsequent eclipse photograph. The remarkable feature of the lower structure is the prevalence of rays completely curving over, and of branching rays, somewhat resembling a frequent form of solar prominence. Few of these reach a height of more than 5' from the limb; above this height the rays are generally straight or more slightly curved.

It is impossible to be certain whether these lower details are really near the limb, or whether they are rays on the nearer or further parts of the corona, seen foreshortened. In the latter case, they could hardly be the extreme ends of coronal rays, as these invariably fade away so much towards their extremities that they would certainly be lost on the dense background. On the whole, the difference of character between the higher and the lower details lends great probability to the view that the latter are really near the limb. Mr. Ranyard considers that the more contorted character of these lower structures indicates the existence of a resisting atmosphere in the lower part of the corona. It seems evident, at least, that many of the curvatures of the coronal rays could not be caused by gravity alone. Still when we consider what an intricate mass of crossing and interlacing rays must be produced by perspective as we approach the limb, we must feel that the question cannot be decided with certainty.

The eclipse occurred at a time of somewhat less solar activity than that of the previous year, Wolf's relative monthly number being 98.0.

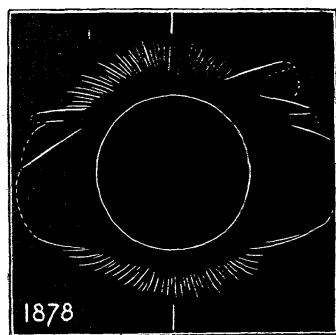


Eclipse of 1875, April 6.

The small size of the photographs taken by Dr. Schuster renders it impossible to make out more than the general character of the corona, and from the same cause the orientation is not very accurately determined. The corona is somewhat symmetrical about a line nearly coinciding with the Sun's axis, the northern and southern polar rifts being very broad and well marked. Four synclinal groups are plainly seen, their axes making angles of more than 45° with the Sun's axis. The polar rifts are filled up, but not to a great height, the polar extension of the corona being only about half the equatorial, where

the greatest height is nearly a solar diameter. The half of the corona lying to the east of the axis is decidedly larger than that to the west, so that the nearly straight lines which bound the corona north and south converge towards the west. Dr. Schuster draws attention to the remarkable similarity between this corona and that of 1874, of which no photographs were taken. He thinks this similarity extends to the irregularity in the symmetry just mentioned; but the want of accordance between the drawings made in 1874 renders this uncertain.

Notwithstanding this general resemblance, the solar activity, as indicated by the sunspots, was less than half as great as in the previous year, Wolf's relative number for April 1874 being 49.1, and for April 1875, 20.5.



Eclipse of 1878, July 29.

The photographs which I have examined are two negatives by Mr. Ranyard, made at Denver, and a series of 9 positive copies on glass of the photographs taken by Professor Harkness and Mr. Rogers at Creston and La Junta. The exposures of Mr. Ranyard's plates were so short that they show but a small extent of corona. A drawing combining the detail of the Creston and La Junta negatives, and showing a further extension of the equatorial rays, from a smaller photograph by Mr. Peers, is given in the "Appendix to the Washington Observations" for 1876. On comparing this drawing with the positives, it does not seem very satisfactory. I can make out as much or more detail on the positives as on the drawing (except the equatorial extension), and no doubt much more would be seen on the original negatives.

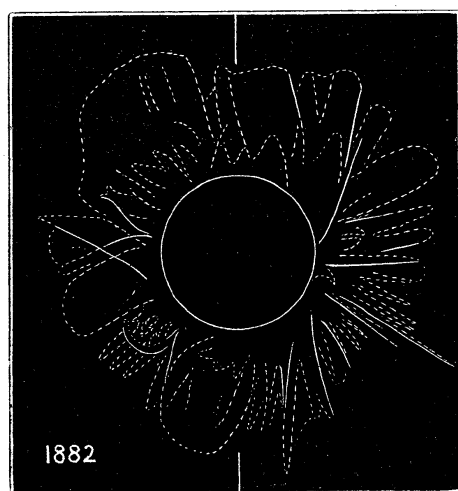
The corona belongs to the same type as those of 1874 and 1875. The equatorial extension greatly exceeds the polar, and both the northern and southern rifts are widely opened, so that their eastern and western boundaries form nearly straight lines tangential to the limb. The northern and southern synclinal groups are so much depressed towards the equator that they appear to coalesce into one great mass, occupying the whole equatorial region. The rifts are filled with fine rays, straight, and nearly radial in the centre of the rift, and becoming more and more curved towards its boundaries. In one rift there are as many as 20 separate rays, remarkably uniform in length and

distance apart, never branching or crossing. The two rifts are almost identical in character, but are not opposite each other; the northern rift having its general axis inclined about 15° towards the east from the Sun's axis, and the southern being more symmetrical with it.

The great equatorial extensions, of which the bases only are visible in the positives, are very symmetrical in detail, but the western mass is the broader, reaching further both to the north and south. These great masses are broadest near the limb, and gradually become narrower, so that their northern and southern boundaries would meet in a point about 2 diameters from the limb on the western side, and rather less on the eastern. These equatorial extensions were, however, observed by Newcomb, Langley, and others, to reach to a distance of at least 12 diameters. They must have been very faint, as in the American drawing, combined from various negatives, they do not extend more than a diameter.

It is a remarkable peculiarity, which I have observed in no other corona, that while at the poles it is split up into a great number of fine rays, the equatorial extensions are broad smooth masses, showing scarcely any detail, even at their extreme edges.

The eclipse occurred at a time of decidedly low solar activity, Wolf's relative number being only 3.3.

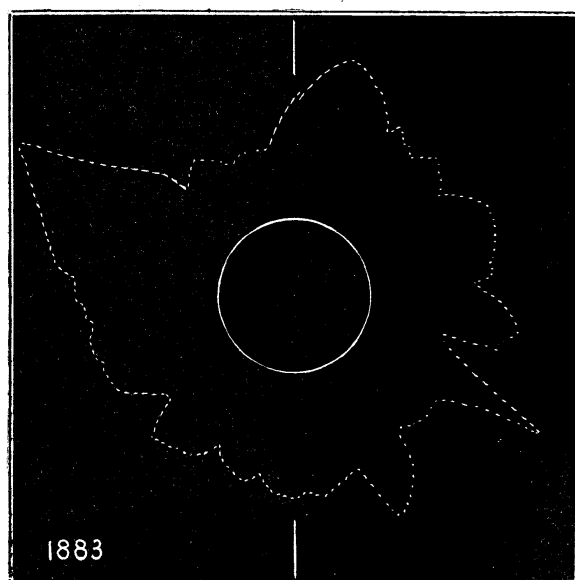


Eclipse of 1882, May 17.

The negatives taken by Dr. Schuster show a large extent of corona, reaching in several places a height of a solar diameter, one straight ray in the south-west extending as far as $1\frac{1}{4}$ diameter. The corona presents none of the features which characterised those of 1874, 1875, and 1878. Although very irregular in detail, it is approximately circular in form, and is entirely without that great difference between the polar and equatorial extensions which had been so striking in the three

last eclipses. At the same time it shows none of that symmetry about a line not very far from the Sun's axis that had been more or less apparent in most previously photographed coronas, and especially in that of 1871. This absence of an axis of symmetry and of polar rifts is its most striking feature. There are groups of synclinal structure, but they are not of a very definite character, and are quite irregularly placed. The solar axis does not pass through the line of least extension, as is almost always the case. The only approach to an axis of symmetry seems to be about a line nearly at right angles with the Sun's axis. The orientation was, however, very carefully made, and in Dr. Schuster's opinion is not more than half a degree in error: it nearly agrees with that adopted by Professor Tacchini.

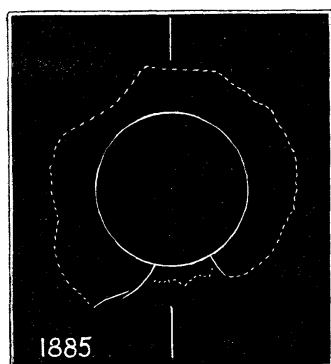
The rays are rather more frequently straight than curved, and there is only one instance of a ray completely curving over: this is in the south-east; it reaches a height of about 12' from the limb. Beneath it are two rays—the only ones showing any traces of a branching structure. There are distinct rifts on the western side, reaching to the limb; but they are more filled up with coronal matter than those of 1871. The rays are in all directions, from radial to tangential, and there are several cases of rays crossing each other, but no clear case of a ray of double curvature. The lower details of the corona are less distinct than in 1871; but this may be due to the great density of the film near the limb, which is common to all dry-plate negatives. The definition of the outer portions is extremely fine. I cannot see any evidence of the distinction between an outer and inner corona, which Dr. Schuster thinks the photographs show. Wolf's relative monthly number of sunspots is 64.5; a remarkable outburst had occurred during the preceding month, for which the number was 95.8.



Eclipse of 1883, May 6.

Successful photographs were taken by M. Janssen, and also by Messrs. Lawrance and Woods. The most prominent feature is an unusually well-marked rift, partly filled with short straight rays, near the north pole of the Sun's axis, from which the general axis of the rift is inclined at an angle of about 30° to the east. On each side of this rift are most characteristic groups of synclinal structure, whose bases meet at the limb: the easternmost shows a double curvature on both sides, but on the western edge this appearance seems caused by the superposition of different rays. There seems no regularity in the arrangement of the rays in the rest of the corona, nor any rift in the south, corresponding to that in the north. The general outline of the corona is somewhat circular, but the two synclinal groups extend farther than any other part. In M. Janssen's long-exposed plate, one of these groups extends nearly as far as two solar diameters, which is the greatest extension shown by any corona photograph. Indeed, M. Janssen says that it is much greater than it appeared to the eye in his telescope.

The solar activity was rapidly decreasing, Wolf's relative monthly number of sunspots being 32.1.

*Eclipse of 1885, September 8.*

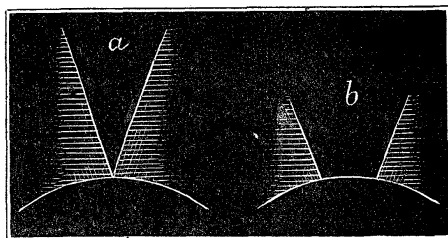
Several photographs were taken of this eclipse, but the weather was generally unfavourable, and few show much detail. The most marked feature is the southern rift, which is broad and well marked, with clear indications of straight rays filling it. The only distinctly synclinal group is to the south-east; its axis makes an angle of about 45° with the Sun's axis, and its extension is greater than any other part of the corona. The western edge of this group presents a double curvature. The other parts of the corona are very irregular, and there does not appear to be any distinct rift on the north corresponding with the southern rift. There is a marked broad depression in the corona, about 35° to the east of the north point of the axis. This depression, and the southern rift, appear to divide the corona into two very unequal parts, the western one being much the greater.

The solar activity, as shown by the sunspots, was diminish-

ing; Wolf's relative monthly number being 83.7 for the month of June, and 39.6 for September.

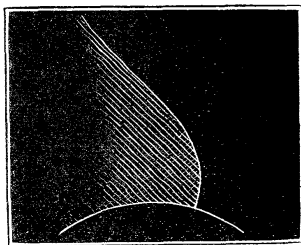
The results of the observations of the eclipses of 1883 and 1886 are in course of publication by the Royal Society, and I have not their permission to describe the details of the corona of these years.

Since the corona entirely surrounds the Sun, and is not a mere fringe as it necessarily seems to the eye, its appearance is greatly modified by perspective. The groups of synclinal structure, when they occur somewhat symmetrically on opposite sides of the Sun, must evidently be regarded as zones of curving rays, the shorter and straighter rays filling the polar rifts, being probably the rays on the nearer or further parts of the synclinal zone seen foreshortened. A curved tangential ray, if curved or inclined in the line of sight, will appear straight and radial but shortened. On the other hand, foreshortening may greatly increase the apparent curvature of a ray. The true point on the Sun from which a ray springs is not seen unless it springs from the limb. The polar rifts must be greatly modified in appearance if they are inclined in the line of sight. It is obvious that a rift which would resemble *a* if actually on the limb would be more like *b* if its axis were directed towards or from the Earth.



The greater apparent density of the corona near the limb must, of course, be largely due to its greater thickness. It is only at the extreme outer limits of the corona that we can see the true character of its rays, as it is only there that they are unaffected by perspective or superposition.

A large proportion of the coronal rays are curved, the curves being of various kinds. It frequently occurs, at the edges of the synclinal groups, that a ray which appears to spring from the limb in a nearly radial direction is abruptly curved, and then straightened, so as to become almost tangential: this is a most characteristic form of coronal ray. Sometimes after it has attained a considerable height it is slightly curved in a contrary direction, as is well seen in 1871, 1883, and 1885.



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Rays completely curving over and branching rays have been mentioned in the description of the corona of 1871, in which they are very numerous; but they are scarcely seen in any other eclipse. Possibly they occur as a rule only near the limb, which portion has never been so clearly shown as in the photographs of 1871.

Dr. Huggins suggests that the curved rays may be caused by matter blown upwards, rising with the smaller rotational velocity of the photosphere from which it started, and appearing to lag behind in its ascent.* But in this case we should expect the curves to be similar in direction and character in any part of the corona, while in fact there is no such regularity, which seems to show that the curvature cannot be the result of this cause alone.

The coronal rays are invariably brighter near the limb, and fade gradually away towards their extremities, where they are sometimes pointed and sometimes spreading. Sometimes they rise from a broad extended base, which character may be more frequent in reality, as the base would be hidden if the ray is not upon or near the limb.

The absolute brightness and extension of the corona during different eclipses cannot be ascertained from the photographs, as they have been taken with various instruments and exposures, and on plates of different degrees of sensitiveness. The earlier collodion photographs probably never showed half the visible corona, while the recent negatives taken on dry plates with long exposures may show more than is visible to the eye.

The coronal matter is very transparent, many rays crossing others which are seen through them.

Nothing that I have seen on the eclipse photographs seems to give the least countenance to any of the meteoric theories of the corona. Drawings such as that of Liais in 1858, representing the synclinal groups as symmetrical cones, would be readily interpreted as streams of meteors passing round the sun; and drawings like Gillman's in 1869, giving innumerable rays all truly radial, might indicate matter falling into the Sun. In the photographs, however, the cones are never symmetrical, and are shown to consist of many rays of various curvatures, while rays that are truly radial are quite exceptional. If the rays were meteor streams sweeping past the Sun we should expect to trace the same streams at opposite sides, while in fact there is no such exact correspondence, even in the most symmetrical corona of 1878.

The detailed structure of the corona seems quite conclusive evidence against Professor Hastings's theory that it is a diffraction phenomenon.

Whatever may be the true cause of the corona, it is impossible for one who has examined the photographs to resist the conclusion that in some way it proceeds from the Sun. The character of the curved rays—especially those which curve com-

* Bakerian Lecture, *Proc. Roy. Soc.*, vol. xxxix. p. 127.

pletely over—the invariably greater brightness of the corona as it approaches the limb, the broad base from which the rays sometimes spring, all seem capable of no other explanation.

Although many observers have spoken of movement of the coronal rays, and have recorded changes of form during totality, there is nothing in the photographs to show that changes of such magnitude as to be visible have taken place in so short a time. Photographs taken an hour apart in 1871 show no visible change, while the clearness of the details proves the appearance of movement to have been an illusion.

I am unable to see in the eclipse photographs any ground for the distinction often drawn between an “inner” and “outer” corona. The principal details can generally be traced down to the limb, and there does not seem any sudden falling-off of the light (except what is caused by occasional strongly curved or foreshortened rays), nor other indication of a want of continuity. It seems to be of the same character throughout. At the same time, it may be true that the lower structures are more frequently of a strongly curved or branching character.

There is no sign of any connection between the coronal rays and the solar prominences.

The only generalisation with regard to the form of the corona which has seemed well supported by the photographic evidence is that of Mr. Ranyard, that there is a connection between the general form of the corona and the solar activity as shown by the number of sunspots. The corona of a sunspot maximum has generally been somewhat symmetrical, with synclinal groups making angles of 45° or less with its general axis. The sunspot minimum coronas show polar rifts much more widely open, synclinal zones making larger angles with the axis, and being therefore more depressed toward the equatorial regions, in which there is usually greater extension. This generalisation is well borne out by the maximum coronas of 1870 and 1871 and the minimum coronas of 1867, 1874, 1875, and 1878. On the other hand, the eclipses of 1883, 1885, and 1886, do not strikingly confirm the theory. The eclipse of 1883, at a time of rapidly decreasing solar activity, shows all the characters of a sunspot maximum corona; the same in a somewhat less degree may be said of 1885 and 1886, at both of which times the solar activity was decreasing. Although the polar rifts were wide in 1886, there was no marked depression of the synclinal groups towards the equator, nor any great equatorial extension, although the relative number of sunspots for August 1886 was only 16.9. Striking, therefore, as the evidence in favour of the generalisation has been in many years, it still seems probable that the form of the corona is modified by other causes at present unknown to us.

It may be that the coronal axis (to use a convenient term) is always inclined at the same angle to the Sun's axis of rotation, and that the apparent changes in its inclination are caused by its being seen from different points of view. Before this question

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can be answered, photographs must be taken at every total eclipse for many years to come. It will, above all, be necessary, however, that the utmost care be taken in the orientation of the plates, that there may not be the slightest doubt as to the position of the Sun's axis. Unfortunately, on several of the eclipse photographs there is great uncertainty on this most important point. It is preferable to take a series of photographs of the solar crescent (by stopping the clockwork in the usual way) both before and after totality, so as to guard against the danger of any slight shift of the instrument.

Sometimes a wire has been placed in the instrument for the purpose of orientation; but wherever this crosses the corona it interferes with the details, and is on that account a disadvantage. In 1886 two pointers were used, one on either side, beyond the limits of the corona; but there is a risk of these not being visible on the plates. If the plate perfectly fit the plate-holder there hardly seems any necessity for a wire.

To prevent mistakes in orientation the plan adopted by Mr. Davis in 1871 was an excellent one. Each of his plates had one corner cut off, corresponding with a small fixed block in one corner of the exposing frame, so that no doubt could afterwards arise as to the position of each plate when exposed.

In the reports of the observations it need hardly be said that the data from which the orientation is obtained should always be fully stated.

It is much to be wished that in future eclipses photographs could be taken which would show the lower details as clearly as the negatives of 1871; I am almost inclined to recommend collodion plates, such as were then employed. The excessive density of the corona near the limb in all the dry-plate negatives obscures the lower details, while the greater coarseness of the grain makes it impossible to use much magnifying power in their examination. At the same time, we ought not to forego the great advantage of the gelatine film in giving the full extension of the corona. It is to be hoped that by some improvement in the preparation of plates both these advantages may be combined.

In the meantime careful drawings would be of great utility if observers would, instead of vainly trying to give a general view of the entire corona, which is quite impossible in the short time at their disposal, restrict themselves to making as exact delineations as possible of the details in some portion only. The general appearance of the corona is admirably given in a good photograph; but this would be most usefully supplemented by detailed drawings of selected portions, especially of the structure near the limb, in which the photograph most frequently fails.

1887, *June 9.*

Physical Observations of Saturn in 1887.

By Thomas Gwyn Elger.

The following observations of the planet were made with an $8\frac{1}{2}$ -in. silver-on-glass reflector by Calver during the months of February, March, and April.

12th February, 9^h to 10^h. Good definition; East wind. Planet beautifully defined with a power of 350. *Rings*.—A. No trace of any division; outer border slightly darker than the remainder. B. Inner edge very dark. Ring gradually increasing in brightness to about midway between the interior and exterior borders. Outer half uniformly bright. C. Both ansæ extremely dark, hardly distinguishable except where it crosses the ball; here it is sufficiently transparent to allow the latter to be seen through it. *Belts*.—The broad equatorial belt is orange-yellow in colour, and sharply defined on its northern edge by a darker band of varying width. Its southern limits are marked by a much fainter band, the intervening space exhibiting a mottled appearance—due to the presence of light spots and markings. About midway between the bluish-grey polar cap and the equatorial zone there is a faint belt, but this region is very indistinct. *Shadow of ball*.—The *f* side of the sharply-defined shadow on B appears to be concave up to Cassini's division, where there is a well-marked notch, apparently coincident with the latter. South of this, on ring A, the shadow follows the curvature of the ball, and seems to be somewhat narrower than any portion of the shadow on ring B. The south limb of the ball is slightly within the outer edge of A.

16th February, 8^h to 9^h. Frosty; wind N.E. Definition variable—not so good as on the 12th. Powers used, 284, 350. *Rings*.—A. Is similar in colour to the polar cap—viz. greyish-blue. There is an evident though faint light line concentric with the ring about midway between the outer and inner edge, but rather nearer the former. It can be traced for some distance on both ansæ, but is more easily seen on the *p* side. B. The shading on this ring becomes gradually lighter from the inner edge to a point about $\frac{1}{4}$ th the apparent width of the belt from the outer edge, where it suddenly ceases, the remainder of the ring being uniformly bright. C. Dark, but distinct on *p* side. *f* ansa nearly indistinguishable. *Belts* less favourably seen than on the 12th.

21st February, 9^h to 9^h 30^m. Definition variable. Power used, 350. *Rings*.—A. No trace of any detail. B. The bright outer edge appears to be of the same tone, but slightly more brilliant than the central portion of the ball immediately north of the equatorial belt. C. Both ansæ very dusky—scarcely distinguishable, except here and there. *Belts*.—North border of equatorial belt sharply defined. Mottled surface evident. Polar and intermediate zone indistinct. *Shadow of ball*.—As on the 12th